

On the other hand, the limit of intensity of rainfall production from convectional overturning is less dependent on the rate of action in the elements of a process than upon the quantity and quality of the supply of warm, moist air and the degree of instability provided before the process begins. Convection is like a conflagration, in that once started it is able to support and extend itself far beyond the initial impulse, through a growth process limited only by factors competent to control the progressive conversion of latent energy into active work.

Small examples will be similar to large ones in that, up to the limit of the energy supply, the process is one of prompt growth from small beginning to maximum possible development. The large examples of convectional overturn may be supposed, in the course of development, to pass through stages of intensity that generally duplicate the characteristics of the smaller disturbances arising under the same seasoned conditions. The by-product of both would be rainfall of similar intensities up to the limits of the lesser disturbance. An intensity series resultant from a collection of samples of convections of all sizes should thus be harmonious within the general limits imposed by seasonal controls.

Colder air, in winter, will set a lower limit of convectional development than that generally obtainable in the warm, moist air of summer. Hence the winter curve of rainfall frequency and intensity lies lower than that for summer.

In the spring the still vigorous cyclonic exchange of polar and equatorial air combines with rapidly rising temperatures and an increasing moisture content of air masses warming near the earth's surface to offer opportunity for development of maximum instabilities. The season favors the conjunction of air currents of great contrast in temperature and humidity, which frequently results in a conversion of general cyclonic energy into the activity of local convections, with rainfall as one of the chief by-products. Thus arise the convectional disturbances of most energetic form, having the largest limits within which their growth can proceed, and thus the curve for April rises to a maximum relation of rainfall intensity to relative frequency.

The largest amounts of rainfall for 24-hour periods occur, at New Orleans, in spring rainstorms (between March and May), in which the quantity of precipitation exceeds even those heavy amounts produced by the passage of well developed tropical storms, which have been responsible for the most intense 24-hour rainfalls in the remainder of the year. The most notable example of the former class of storms is that of April 15-16, 1927, when 14.01 inches of precipitation occurred at New Orleans in one day's rain. The general characteristics of this type of rainstorm are worthy of further study, to place them into correct relation to the major movements of the atmosphere which must attend them.

## METEOROLOGICAL SURVEY OF PROPOSED SITES FOR THE SAN FRANCISCO MUNICIPAL AIRPORT<sup>1</sup>

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[Author's abstract]

Many sites for the proposed San Francisco municipal airport were suggested and the merits of each were discussed at numerous hearings before the Board of Supervisors of the City and County of San Francisco. The opinions of experienced Government and civilian flyers were obtained, but they differed so widely, particularly as to weather conditions, that it was impossible to agree upon a site and it was therefore decided to develop a temporary airport, pending the results of a meteorological survey of all proposed sites, on which to base final judgment in selecting a site for the permanent airport. In cooperation with the city engineer's office, the Weather Bureau was asked to outline the survey and to supervise the work during its progress.

### PHYSICAL REQUISITES OF AN AIRPORT

The three primary requisites of an airport are (1) favorable climatic conditions, (2) adequate size, and (3) accessibility. While nearness to the metropolis is desirable, this factor has little weight in determining the best possible location for an airport unless the two more important requirements, i. e., suitable climatic conditions and adequate size, have first been satisfied. The airport must be of sufficient size to provide for buildings and still leave ample room for the operation of aircraft. Runways must be oriented so that planes may take off or land into the wind and they must be sufficiently long to provide a safety factor in the operation of transport planes.

Important as size and nearness are to the problem of airport location, the basic physical requisite is meteorological

suitability. Hazards due to weather must be reduced to the lowest possible minimum, which can only be done by choosing the location that has the most favorable meteorological conditions. All other considerations may therefore be disregarded if a proposed location for an airport is unfit for safe landing and scheduled flying because of meteorological unsuitability.

### AVAILABILITY OF SITES MEETING REQUIREMENTS

No site within the city and county of San Francisco was suitable for development as an airport. With water to the west, north, and east, the search for sites was necessarily directed southward along the peninsula. Many possible sites were offered and six specific sites were chosen for consideration in the meteorological survey.

Site No. 2 is located just south of what is locally known as South San Francisco, and this location was favored by many because it is nearest to San Francisco. The selection of this location was opposed by others on the grounds that it is bordered by a high tension power line, that rough air is found there owing to the proximity of the San Bruno Mountains and that the site is frequently covered with fog.

Site No. 6 is located 1 mile south of site No. 2 and is the one selected for the temporary airport, known as Mills Field. Those in favor of this location claimed that it is far enough south to escape fog and unfavorable winds attributed to site No. 2 and that it is favorably situated with respect to obstructions. Opponents of this site claimed that more favorable weather conditions would be found still farther south.

Sites Nos. 1 and 4 lie immediately south of site No. 6 and may be considered together since they are separated by the highway only. Site No. 1 is obviously deficient

<sup>1</sup> Complete report, with tables and figures, is on file at Weather Bureau Office, San Francisco, Calif. It is expected that it will later be published in full as a public or private document.—E. E. E.

because of its restricted area and the proximity of the power line, and for these reasons is inferior to site No. 4. Proponents of these sites claimed for them more favorable weather conditions that would be found at sites farther north and that they were more suitable than sites farther south on account of being nearer to San Francisco.

Site No. 5 lies to the northeast of the city of San Mateo and is entirely under water at the present time. Superior climatic conditions were claimed by the proponents of this site, while excessive cost of development, proximity of the power line and remoteness from the city were among the objections.

Site No. 3, located at Beresford, is the farthest south and farthest inland from San Francisco Bay. It was therefore claimed that there is less fog in this locality. Opponents of this site pointed out that its area is inadequate and incapable of extension, that planes would be taking off over well-settled territory and that it is unnecessarily far from San Francisco.

Granting that each of the proposed sites possessed two of the three primary requisites for an airport, i. e., that each was of adequate size and that each was sufficiently close to the center of urban activity, there remained the vital question of suitable climatic conditions. Which one excelled in this respect?

Statements relative to weather conditions along the peninsula could not be supported by any tangible facts or figures because no data were available for any of the sites under consideration. The statements, then, represented only opinions which might be erroneous or biased. The conclusion was reached that the only rational way to decide the matter was to make weather observations at all the proposed sites for one year and let the facts speak for themselves.

#### METEOROLOGICAL CHARACTERISTICS AFFECTING AVIATION

Among the meteorological elements that affect the operation of aircraft, fog presents the greatest menace. It is therefore obvious that the less fog an airport has, the better is it adapted for commercial use. On many afternoons during the summer, a "blanket fog" forms over the ocean off San Francisco. As the afternoon advances, the fog bank moves landward, is forced to ascend, and lies along the summit of the highest range of hills in the San Francisco Peninsula. If this fog moves inland during the afternoon or night, it is commonly referred to as "the fog coming in," even though it may be, and usually is, 500 to 1,000 feet above the surface of the earth. The formation is therefore stratus cloud and not fog unless it descends to the earth's surface.

Horizontal visibility is a meteorological factor to which little importance was formerly attached but which has become increasingly important with the development of commercial aviation. Visibility defines the visual limits imposed by fog, haze, smoke, dust or precipitation and, especially in the vicinity of an airport, good visibility is desirable.

Ceiling is the altitude of the cloud canopy when the sky is largely or entirely covered; a measure of vertical visibility. If the clouds are very low, they constitute a menace to aerial navigation second only to dense fog, and low ceilings near an airport should be avoided if possible.

Instrumental equipment for observing surface weather conditions at meteorological stations other than the one at Mills Field consisted of an anemograph, sunshine recorder, and rain gauge at each station; the headquarters station at Mills Field also had a barograph sling psychrometer, and maximum and minimum thermometers. Because of the importance of records of

fluctuations in wind velocity and direction in considering an airport site, Dine's anemographs were chosen for the meteorological survey and continuous records of wind velocity and direction were thus secured. The sunshine recorders were of the spherical lens type in which the record is burned on a strip of cardboard. Sunshine is of no importance in itself so far as airport operation is concerned but the sunshine records were used in connection with records of fog and cloudiness. The 8-inch rain gauges, maximum and minimum thermometers, sling psychrometer, and barograph were all of the ordinary type.

Noninstrumental observations were taken daily at approximately 9 a. m. at each of the outlying stations, noting the amount and kind of clouds and their direction, the height of the ceiling, if any, the range of visibility, and the occurrence of rain, fog, smoke, haze, etc. Hourly records of all these phenomena were kept at Mills Field.

Aerological observations formerly conducted at the San Francisco office of the Weather Bureau were transferred to the airport and served the dual purpose of providing information for the Weather Bureau and for the meteorological survey. The two-theodolite method was used in the balloon observations for the survey, the readings being made at half-minute intervals in order to obtain more detailed information. The demands of the survey required observations at several sites in rotation and it was necessary to devise a means of transporting the personnel and equipment from place to place and also provide for filling balloons in the field. Equipment for inflating the balloons and specially constructed boxes for transporting the theodolites were installed in an automobile which was also used for making the daily round of the stations. Other preliminary work included the devising of forms for compiling data, the building of a theodolite observation platform, installation of telephones, the erection of an instrument shelter and rain gauges, clearing of firebreaks around the outlying meteorological stations, selection and surveying of 10 base lines for two-theodolite observations in five different locations, and the installation of four anemographs and four sunshine recorders.

Direction, speed, and gustiness are the three factors in surface wind forces that must be investigated before choosing the location of an airport. Turbulence of the air over and near the airport must also be considered. The layout of buildings and runways is determined by reference to the prevailing wind direction, and movements of the air affect not only the ease of operation of an airplane but the safety of the operation as well. Wind direction determines the direction in which a plane is taken off or landed. In either case, the plane is headed directly into the wind. The orientation of the principal runway should be such that it will permit the maximum number of take-offs to be made over favorable territory where a pilot will have a fair chance of landing with a "dead stick" if necessary. When a large number of planes are using the field, frequent shifts in wind direction cause some to be landing or taking off in one direction and some in another, and the possibility of collision is increased. An airplane in flight depends for its dynamical support upon its speed in relation to the air and a moderate wind is therefore an advantage when either landing or taking off, providing it is steady in direction and velocity.

The air is a gaseous fluid which is constantly in motion with whirls, eddies and all sorts of eccentric motions occurring within it in much the same manner as in flowing water. These irregular motions constitute turbulence, a phenomenon that makes its appearance in fluids,

gaseous or liquid, when they flow past solid surfaces or even when two streams of the same fluid flow over or past one another. Changes in the horizontal component of wind movement at the earth's surface are much larger than changes in the vertical component, and these horizontal changes constitute gustiness, the relatively small changes in the vertical component being ignored. Turbulence of the air is of no consequence at high levels but is inimical to ease and safety of flying at low altitudes.

Rain affects the landing surface of an airport and decreases visibility but, in the San Francisco Bay region, records of rainfall and temperature are chiefly of value to the engineer in planning drainage and heating facilities. Thunderstorms are inconsequential in this region.

#### ORGANIZATION AND EQUIPMENT OF SURVEY

The purpose of the meteorological survey was to collect data that would indicate, from a climatic standpoint, which of several proposed sites was most suitable for airport purposes. It was therefore necessary to investigate and keep records of those meteorological elements which most affect the successful operation of a modern commercial airport. It was the first survey of its kind. Some cities, without preliminary investigation of meteorological conditions, have chosen unsuitable locations for airports; sometimes there has been only one possible location.

The personnel comprised four men; two employed by the city and two by the Weather Bureau. The latter were assigned to Mills Field to perform the aerological and airways duties incident to the status it then held as the terminus of the air mail lines, and other services in connection with the survey were incidental to their official duties at the airport. Had it not been for the cooperation of the Weather Bureau, the meteorological survey of proposed airport sites would have been impossible. The Chief of the Weather Bureau approved the cooperation of Federal employees, allowed the use of instrumental equipment, and selected the meteorologist who conducted the survey. The closest possible cooperation was maintained between the San Francisco office of the Weather Bureau and the city's meteorological personnel.

#### AIRPORT SITES AND METEOROLOGICAL STATIONS

The six proposed sites included in the meteorological survey lie on the east side of the San Francisco Peninsula in a narrow strip 10 miles long. The topography of the peninsula has marked local influences on the behavior of fog and wind, the two climatic factors that are most significant in determining the best possible location for an airport. Numerous ranges of hills extend along the peninsula, the axes of all the main ridges lying in a northwest-southeast direction. Between two of these ridges is a gap which constitutes the lowest path across the peninsula, wherein the elevation of the land averages less than 100 feet, with hills rising to elevations of 500 to 1,300 feet on either side.

The climate of the San Francisco Peninsula is characterized by mild temperatures, abundant sunshine, marked wet and dry seasons, and frequent summer fogs of marine origin. The prevailing drift of the surface air is from west to east and the velocity of the westerly winds is greatly augmented on summer afternoons by the radical difference in density between the cool, ocean air and that of the heated interior. In addition to the high fog or stratus cloud layer so frequently present on summer mornings, radiation fog sometimes occurs in the San Francisco Bay region during the winter.

In order to obtain data on which to base a comparison of the several sites from the standpoint of meteorological fitness, it was necessary to establish four meteorological stations. The headquarters were at Mills Field, or site No. 6, and data secured there were also used as an index of weather conditions at the two adjoining sites, Nos. 1 and 4. The wind vane was placed on a 20-foot mast mounted on the roof of the building, with the thermometer shelter, rain gauge, and sunshine recorder in suitable locations outside. Each of the three other meteorological stations included a house 8 feet square and 10 feet high with the anemograph support and sunshine recorder on the roof and a rain gauge on the ground nearby. These stations were located on sites Nos. 2, 3, and 5. Five locations were selected for making 2-theodolite pilot balloon observations and a pair of base lines was laid out in each location, one pair serving for two sites, Nos. 1 and 4.

#### RESULTS OF INVESTIGATIONS

In presenting the results of the investigations made during the year, each meteorological element was considered in its relation to each of the several proposed sites, the sites being weighed in geographical order from north to south. Although continuous records of the various meteorological elements were made at Mills Field, continuous records for other stations were available only for those elements which were recorded by means of automatic instruments. The results of the daily observations were used as a basis for comparing those meteorological elements that were recorded from eye observations. Fog was recorded from eye observations but the sunshine records were used to supplement these in indicating the time the fog began or ended. Dense fog was observed at sites Nos. 1, 4, and 6, 8 times in 295 observations and at each of the other stations 9 times. Fog was observed at one or more stations on 14 dates and four types of fog distribution were represented, which we may call general, northern, southern and local.

Owing to the observational limitations of the survey, it was necessary, in order to make a comparison of fog conditions at the several proposed sites, to adopt some number system as an index of relative foginess. Numbers were assigned to indicate the order of dissipation of fog at the several sites and, considering all fogs observed, site No. 6 proved to have less fog than any of the others by the ratios 18:27, 18:23, and 18:27. Further comparison was made by totaling the duration of all fogs after 7 a. m. It was found that in most instances fog dispersed at site No. 6 earlier than at the others and that the total duration of fog was least at that site.

Visibility as determined at the daily observations was represented graphically and in tabular form, by days and months, and the records made at site No. 6 indicated somewhat better visibility than did those made at any other proposed site.

A scale was adopted for indicating ceiling, as follows:

- O..... Surface (dense fog).
- A..... Less than 500 feet.
- B..... 500 to 1,000 feet, inclusive.
- C..... Above 1,000 feet.
- U..... Unlimited.
- X..... Broken.

From the daily observations and from the sunshine records, it was found that on summer mornings the clouds dissipated earliest at the most southerly site and latest at the most northerly, but that during the winter there was little difference in the height of the ceiling at the several suggested sites.

Continuous records of wind direction were tabulated hourly to 16 points of the compass at all four meteorological stations. The percentage of time the wind blew from each direction was computed. It was discovered that the wind direction at site No. 6 was more constant than at any of the other proposed sites. Since more flying is done in the daytime than at night, the prevailing direction for each site, shown in percentage of time, was computed for the period 6 a. m. to 6 p. m. and it was ascertained that constancy of wind direction during the daytime was more marked at site No. 6 than at any of the others and that, in general, the directions were similar to those prevailing for the entire 24 hours. The greatest freedom from sudden changes in wind direction was found at site No. 2, where the average maximum abrupt change in wind direction was  $38^\circ$ ; at sites Nos. 1, 4, and 6,  $43^\circ$ ; at site No. 5,  $45^\circ$  and at site No. 3,  $92^\circ$ . Sudden changes in wind direction as large as  $135^\circ$  occurred frequently at site No. 3.

From the automatic records of wind velocity, it was learned that winds from the WNW. had the highest average velocity. During the summer months, wind velocities increased shortly before noon when the sea breeze began to blow and reached their peak at about 4 p. m. Wind movement averaged greatest at site No. 2, followed in order by site No. 5, sites Nos. 1, 4, and 6, and site No. 3. Extreme wind velocities were tabulated for each hour and the proposed airport sites ranked in order from north to south as regards freedom from high wind velocities.

Excessive gustiness of the wind being an undesirable feature in an airport, a knowledge of maximum amplitudes of quick fluctuations in wind velocity and of sudden changes in wind direction was required for each site. Gustiness in winds of less than 10 miles per hour was ignored. Data on maximum amplitudes of rapid fluctuations in wind velocity were obtained by considering such a fluctuation to be represented by the longest vertical line registered during each hour on the anemograph sheets, and it was assumed that the record made by a vertical line would occur within the period of time that would embrace the landing or take-off time of an airplane. Maximum fluctuations for each hour were tabulated and monthly averages of gustiness due to rapid fluctuations in wind velocity were computed.

Maximum fluctuations in wind velocity, however, do not present a complete index of gustiness so far as its effect on airplane manipulation is concerned because quick variations in wind direction, even when unaccompanied by changes in velocity, have an effect on an airplane in flight comparable to fluctuations in wind velocity, depending upon the amplitude and suddenness of the variation. Assuming that a change in direction as indicated by a vertical line on the anemograph sheet occurs practically instantaneously, if  $V$  is the mean wind velocity and  $A$  the angular change in direction, the effect of  $A$  will be the same as a change in velocity equal to  $V(1 - \cos A)$ , of gustiness  $(G) = V(1 - \cos A)$ . Monthly

averages of gustiness (in m. p. h.) due to sudden changes in wind direction were computed.

Considering gustiness induced by both causes—i. e., that due to velocity changes and that due to direction changes—the least average gustiness occurred at site No. 5, 6.2 m. p. h., followed by sites Nos. 1, 4, and 6, 6.5 m. p. h.; site No. 2, 6.9 m. p. h. and site No. 3, 10.8 m. p. h.

Turbulence involving air movements with marked vertical components at ordinary flying levels may be inferred by means of pilot balloon observations in which two theodolites are used. The ascensional rate of 180 meters per minute was used because it was necessary to combine the two-theodolite observations for the use of the survey with the single-theodolite observations required by the Weather Bureau, and departures from this rate could only be due to turbulence. Departures from the normal ascensional rate were determined for each half-minute period. The least average variation from the normal ascensional rate, and hence the smoothest air, between the surface and the 1,000-foot level occurred over sites Nos. 3 and 6, while above the 1,000-foot level the greatest freedom from turbulence occurred over site No. 6. The strongest vertical air current that was found was downward (3.8 m. p. s.) over site No. 2 at an altitude of 3,700 feet.

Slight variations in precipitation were found at the various sites. By comparison with records for San Francisco, it was estimated that precipitation for the year was somewhat subnormal and that the temperature averaged a little above normal.

#### CONCLUSIONS AND RECOMMENDATIONS

It was shown that fog occurred fewer times at site No. 6 than at any of the other proposed sites, that the total duration of fog after 7 a. m. was least there, and that, on the average, site No. 6 had the best visibility. Site No. 3 possessed an advantage over the more northerly sites as regards the duration of low ceilings in summer. Constancy of wind direction was most pronounced at site No. 6, and a runway oriented according to the prevailing wind would permit the maximum number of take-offs to be made over favorable territory, which would not be true at the other proposed sites, excepting No. 4.

Variation in wind direction from moment to moment at site No. 6 was less than at any other proposed site except No. 2. The surface wind velocity at site No. 6 was more advantageous for the operation of aircraft than at site No. 2 and equally with site No. 5, although smaller average wind velocities and greater freedom from high winds occurred at site No. 3. The latter site had a distinct disadvantage on account of excessive gustiness. No other proposed site had less turbulence than site No. 6.

All factors considered, no other suggested site appears to have as favorable meteorological conditions as site No. 6, and this site, the location of the temporary airport, is therefore recommended, as a result of the meteorological survey, as the most suitable one for the permanent location of the San Francisco municipal airport.